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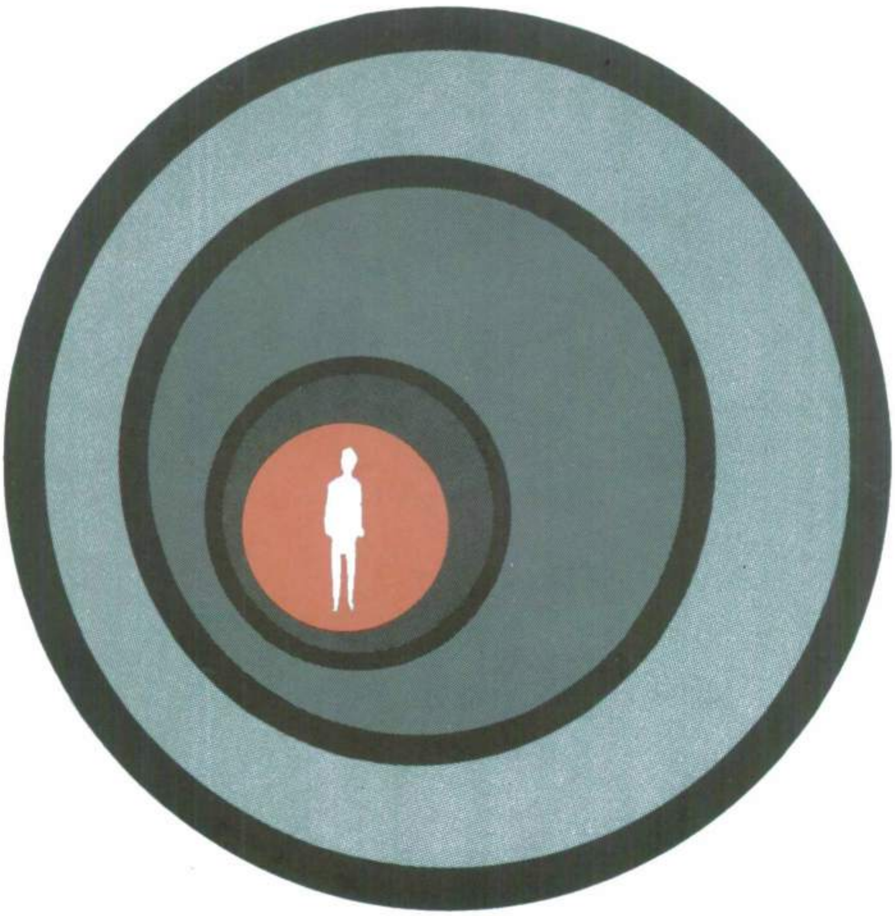
CURRENT SIMULATOR SUBSTITUTION PRACTICES IN FLIGHT TRAINING



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The reduction of flight hours following the introduction of new or additional simulator training was noted for 25 programs occurring during the past 10 years. These demonstrations were felt to be typical of the practices existing in the general aviation, commercial airline, and military environments. The percentage reduction of the original in-flight syllabus (effectiveness) and the ratio of simulator hours required per in-flight training hour replaced (efficiency) were computed for each demonstration.

20. ABSTRACT (continued)

These data were examined in terms of the three environments noted above. The demonstrations were also classified according to various factors such as category of training (instruments vs. contact), student experience levels (undergraduate vs. designated aviators), simulator sophistication (use of motion and visual systems), and type airframe (helicopter, jet, or transport). The median values of effectiveness and efficiency for such classificatons were computed. The limitations of current simulator substitution data were delineated.

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FOREWORD

The support provided by the various training units identified in this study is gratefully acknowledged. The individuals interviewed were extremely knowledgeable in the issues and problems associated with substituting simulation for in-flight training and were candid in their discussions.

We are indebted also to a number of Training Analysis and Evaluation Group personnel, including Robert F. Browning, Paul G. Scott, and Eugene R. Hall for contributions early in the study, and to Dr. Myron M. Zajkowski for his efforts in structuring, refining, and editing the presentation of the material.

Finally, we are especially pleased to acknowledge the counsel and support of Dr. Alfred F. Smode. He conceived the need for this type of study and was instrumental in its conceptualization and completion.

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SECTION I

INTRODUCTION

Providing simulator training as a surrogate for in-flight training is on the increase in the military. In large part, this has come about through a developing awareness that simulators can be employed to advantage in flight training. Several specific reasons for this trend can be identified.

- Substantive advances in simulation technology are reflected in the increased sophistication and fidelity of visual and motion systems and in the dynamics and control responsiveness of the simulators.

- Concomitantly, gains in the strategies of training have shaped new and impressive utilization capabilities for flight simulators.

- Substantial economies accrue when flight simulators are employed efficiently in training programs. The costs of aircraft operation vis-a-vis simulators have been excessive due to the recent increases in fuel and maintenance expenses. It is estimated that aircraft hourly operation costs can be 10 times those of the corresponding simulators.

- Operational considerations generally favor simulators. Foremost among these are mechanical reliability, availability of training time, compression of training sequences, and compromises due to the flight environment; e.g., safety, weather, and airspace congestion.

The combination of engineering sophistication and the development of systematic student-centered instructional techniques places the simulator quite realistically in contention as a major flight training medium in today's military environment (Smode, 1974). To these should be added the positive feature of economic advantage. While the differentials between simulator and aircraft construction, utilization, and amortization are subject to various interpretations, the evidence generally indicates significantly lower costs for training when the simulator is used efficiently in conjunction with the aircraft. The emphasis on fuel economy, as reflected in a recent Department of Defense (DOD) directive[1] calling for a 25 percent reduction in hours flown by FY 1981, has intensified the interest in the costs savings associated with simulator substitution practices.

Unfortunately, a useful body of data to provide guidelines on substitution of simulator training for in-flight training does not exist. Operating

[1] As acknowledged by CNO letter ser 596/122817 of 5 May 1975.

practices in this regard are also sketchy. The evidence, at best, indicates that the extent of and confidence in substituting simulator training for in-flight training are a function of simulator fidelity, instructional strategy, student skill level, training tasks, aircraft type, and training environment.

It is not the intent of this report to examine the many facets of the aircraft/simulator controversy or to examine the generic issue of transfer of training. The latter topic has been well addressed in a number of recent documents (see, for example, Smode, Hall, and Meyer, 1966; Hall, Parker, and Meyer, 1967; Micheli, 1972; Blaiwes, Puig, and Regan, 1973; Caro, 1973; Caro and Prophet, 1973; Williges, Roscoe, and Williges, 1973; Valverde, 1973; Roscoe, 1974; Hopkins, 1975; Caro, 1976). For the most part, these documents organize available research and identify trends in data. The intent here is straightforward and relatively simple. It is to determine current practices in substituting simulator training for in-flight training.

PURPOSE

This report provides a sampling of current practices in the substitution of simulator training for in-flight training. This work is a follow on to an initial quick reaction tasking of the Training Analysis and Evaluation Group (TAEG) by the Chief of Naval Education and Training (CNET) wherein an "immediate" response was sought on current military users' views on realistic substitution ratios. In this quick inquiry of selected military units, a wide range of ratios was reported which suggested that in-flight training was arbitrarily being replaced by simulator time. Consequently, the present study was undertaken to provide a detailed examination of current simulator substitution practices. The goal of the study was to obtain a useful understanding of current substitution practices and to determine the availability of this information. Data collection was initiated in January 1976 and essentially completed in September 1976. Information was obtained by direct solicitation during visits to operational units and by telephone interviews. Also, recent literature, unpublished data, and other information obtained from individuals currently involved in simulator training were used in the review.

No attempt is made to provide a methodological or theoretical critique of practices in individual demonstrations. However, based on an overview of these data, a number of deficiencies related to quality of the data, interpretation of the data, and methodologies are presented.

ORGANIZATION OF THE REPORT

In addition to this introduction, section II of this report provides background information on substitution formulas used to describe the data. The two substitution formulas utilized in the report are percent flight syllabus reduction and flight substitution ratio. Explanatory information is provided to facilitate the understanding of data treatment in subsequent sections. Section III catalogs data on the substitution practices from 25 demonstrations into 3 major classes of users: general aviation, commercial, and military. Elaborations of the curriculum, training practices, or equipment are provided only when such additional information serves to aid the interpretation of data in the tables. The military user demonstration data are presented by type of airframe: jet, helicopter, and transport. Section IV summarizes this data as a function of the factors of training category, user class, aircraft type, student experience, simulator visual and motion capabilities, and curriculum features such as the use of special syllabi or part-task trainers. Section V contains a summary and discussion of major observations and deficiencies gleaned from the data.

SECTION II

SUBSTITUTION FORMULA

This section contains an explication of the formulas which are currently used to describe the relationship between simulator substitution hours and in-flight hours. They are used to summarize and compare the demonstration data provided in this report. Therefore, familiarity with the assumptions underlying these formulas and the associated computational methods is required to facilitate understanding the information presented in sections III and IV.

FORMULAS

Three types of computational formulas in current use are presented in table 1. The first formula (Percent Flight Syllabus Reduction) expresses the overall ability of the simulator to reduce the amount of in-flight training in the syllabus.

TABLE 1. WAYS OF MEASURING TRANSFER

Computation	Formula
Percent Flight Syllabus Reduction	$\frac{\text{Original Flight Hours - New Flight Hours}}{\text{Original Flight Hours}} \times 100$
Flight Substitution* Ratio (FSR)	$\frac{\text{New Simulator Hours - Original Simulator Hours}}{\text{Original Flight Hours - New Flight Hours}}$
Transfer Effectiveness* Ratio (TER)	$\frac{\text{Original Flight Hours - New Flight Hours}}{\text{New Simulator Hours**}}$

* Although these values are defined as a ratio, in subsequent sections of the report, only the quotient of this calculation is reported.

** Some authors use the new simulator hours minus original simulator hours as the denominator where the original group received some simulator training time (i.e., when there was no flight-only group).

The larger the positive value of syllabus reduction, the more effective the simulation. Syllabus reduction can also be negative when the simulator group received more flight training than the group(s) receiving none or smaller amounts of simulator training. The percent flight syllabus reduction is sometimes simply referred to as percent savings.

The Flight Substitution Ratio (FSR), the second formula in table 1, refers to the ratio of increase in simulator hours to the decrease in flight training hours. The FSR is the rate at which flight time is being replaced by the simulator. Thus this term reflects efficiency of the device. The smaller the value of a positive FSR, the more effective the substitution. A negative FSR may be obtained when a device is used more effectively and results in decreases in both simulator and in-flight hours. A negative FSR may also occur when increased simulator hours are associated with an increase in flight hours.

The third formula in table 1, Transfer Effectiveness Ratio (TER), expresses transfer as a ratio of flight hours saved to the time spent in the simulator. This ratio is essentially the reciprocal of the FSR. Therefore, only FSR is reported in the tables in this report. The concept of TER is discussed in detail in Roscoe (1971).

In accounting for training time in the calculation of substitution values, two special conventions were employed. First, the inclusion of simulator time for the original group in the calculation of substitution ratios was based on a judgment of the effectiveness of this time. This judgment was made in all cases, but only in one case did it lead to the exclusion of the original group's simulator time.

The second convention dealt with the calculation of substitution of values in multipiloted simulators such as those used by the airlines and some military environments. In these situations, students normally occupy both pilot and copilot positions. One student occupies the "training" position while the second student performs the role of the other crew position. During in-flight instruction, students occupy only one of these positions. Total time in both simulator positions was used in the substitution calculations. However, the relevance of time spent in the nontraining position might be questioned. This is especially true for military students since they are generally not tested on items learned in that position.

SECTION III

CATALOG OF SIMULATION SUBSTITUTION PRACTICES

Data from the three major classes of aircraft simulation users are cataloged in this section. Organizing the results of the demonstrations according to the classes of (1) General Aviation, (2) Commercial, and (3) Military users permits both interclass and intraclass comparisons. The term "demonstration" is used in this report to refer to comparisons of two training programs for a particular type aircraft. Typically this involves comparing in-flight training hours before and after the installation of a new simulator, or the increased use of an existing device.

The tables in this section all follow the same format. First, the organizational environment, the type of tasks and students involved, and the aircraft and simulator utilized are described. For all demonstrations, the information provided herein is as detailed as that reported in the primary sources. Second, the raw training times data are presented in a form amenable to the use of the computational formulas described in section II. Finally, simulator substitution results are reported in the form of percent flight syllabus reduction (effectiveness) and flight substitution ratios (efficiency). The discussion which follows amplifies information depicted in various tables in this section. The reader may wish to refer to the appropriate tables for the details.

GENERAL AVIATION

These data are based on demonstrations which typically use private pilots with relatively limited flying experience, unsophisticated simulators, and light aircraft. They are examined here because of their experimental rigor and innovativeness in research methodology.

As expected, demonstrations 1 and 2 in table 2 indicate that a current generation aviation trainer (GAT-1)[2] having a higher fidelity to the modern aircraft achieved better substitution results than a post-World War II vintage device (AN-T-18). The large differences in results of demonstrations 2 and 3 were due presumably to differences in the instructional strategies and controls. Consistent with general trends, the instrument training tasks in demonstration 4 produced better substitution results than basic aircraft handling tasks in demonstration 3.

[2] The GAT series are general aviation trainers. The GAT-1 simulates a single-engine light aircraft; the GAT-2, a piston-powered light twin. Reference to general aviation trainers and GAT, a registered trademark of the Link Division of Singer, Inc., does not constitute an official endorsement or approval by the Navy Department of a commercial product.

TABLE 2. GENERAL AVIATION DEMONSTRATIONS

ENVIRONMENT			SUBSTITUTION DATA				COMPUTED RESULTS	
ORGANIZATION/ REFERENCE	TASK/ STUDENTS	AIRCRAFT/ SIMULATOR	ORIGINAL FLIGHT HOURS	NEW FLIGHT HOURS	ORIGINAL SIMULATOR HOURS	NEW SIMULATOR HOURS	PERCENT FLIGHT SYLLABUS REDUCTION	FLIGHT SUBSTITUTION RATIO
1. University of Illinois/ Povenmire and Roscoe (1971)	Private Pilot Course/Flight naive students	Piper Cherokee PA-28/Link AN-T-18	45.5	36.5	0.0	11.0	20	1.2
2. University of Illinois/ Povenmire and Roscoe (1971)	Private Pilot Course/Flight naive students	Piper Cherokee PA-28/Link GAT-1	45.5	34.5	0.0	11.0	24	1.0
3. Ohio State University, Middle Tennessee State University, Miami-Dade J. C./ Crook (1967)	Private Pilot Course/Flight naive students	Four unspecified light aircraft/ Unspecified currently available generalized ground trainers	42.3	35.4	0.0	16.0	16	2.3
4. Ohio State University, Middle Tennessee State University, Miami-Dade J. C./ Crook (1967)	Instrument Rating Program/ Civilian pilots having minimal previous instrument time	Four unspecified light aircraft/ Unspecified currently available ground trainers	40.0	20.8	0.0	17.0	48	0.9

COMMERCIAL

These data are based on demonstrations which typically use highly experienced pilots, sophisticated simulators, and jet transport category aircraft. They are included here because they represent a comparatively high level of refinement in simulator utilization. The data obtained from these sources are also characterized by a high degree of reliability. Only a restricted sample of commercial demonstrations is presented here in the belief that they are representative of industry practice. Demonstrations 5 and 6 in table 3 reveal the successful outcome of airline substitution practices with FSRs of 1.1 and 0.9 respectively and 90+ percent syllabus reductions. In contrast to these demonstrations, which involved jet transport captain transition training, demonstration 7 utilized corporate pilots. The latter demonstration achieved a lesser degree of substitution.

MILITARY

These data are based on demonstrations drawn from all branches of military service. Involved are military pilots, a wider range in the sophistication of training devices, and a variety of military aircraft. The sample of training demonstrations presented here are representative of current military practice. Most of the demonstrations were done under the cognizance of organizations which specialize in training system development and evaluation. However, data were generated from several demonstrations which were subject to operational expediencies and not to formal monitoring and/or control. This discussion of military practice is organized according to three basic categories of aircraft: helicopters, jets (center-line thrust fighter-type trainers), and transports (noncenter-line thrust piston, turbo-prop, and jet powered).

HELICOPTERS. These substitution practices refer to demonstrations 8 through 12 in table 4. Demonstration 8 employed the Army Synthetic Flight Training System (2B24), a high-fidelity device. This demonstration achieved substitution levels approaching those obtained by the commercial airlines. The following factors were thought to enhance the success of this demonstration: (1) the training primarily involved instrument procedures which have been generally shown to have high transfer, (2) the program employed a curriculum designed to exploit the simulator's unique capabilities. In addition it should be noted that the previously used device (1-CA-1) provided negligible transfer to the helicopter (Isley, Caro, and Jolley, 1968). Therefore, 1-CA-1 time was ignored in calculating the FSR presented here.

Demonstrations 9, 10, and 11 show a wide variation in substitution and considerably less success than demonstration 8. In demonstrations 9 and 10 dramatic differences in savings were obtained even though the

TABLE 3. COMMERCIAL DEMONSTRATIONS

ENVIRONMENT			SUBSTITUTION DATA				COMPUTED RESULTS	
ORGANIZATION/ REFERENCE	TASK/ STUDENTS	AIRCRAFT/ SIMULATOR	ORIGINAL FLIGHT HOURS	NEW FLIGHT HOURS	ORIGINAL SIMULATOR HOURS	NEW SIMULATOR HOURS	PERCENT FLIGHT SYLLABUS REDUCTION	FLIGHT SUBSTITUTION RATIO
5. American Airlines/ American Airlines (1976)	Transition Training Course/ Airline captains	Boeing 707/Link simulator	18.3	1.3	0.0	18.4	93	1.1
6. American Airlines/ American Airlines (1976)	Transition Training Course/ Airline captains	Boeing 727/Link simulator	20.6	1.0	0.0	18.6	95	0.9
7. American Airlines and Flight Proficiency, Inc./American Airlines (1976) and Flight Proficiency, Inc. Literature (1976)	Two corporate pilot FAA Type Rating Courses/ Commercial pilots	Cessna Citation/ Link simulator, modified	9.0	2.5	0.0	18.0	72	2.8

TABLE 4. MILITARY DEMONSTRATIONS: HELICOPTERS

ENVIRONMENT			SUBSTITUTION OATA				COMPUTEO RESULTS	
ORGANIZATION/ REFERENCE	TASK/ STUOENTS	AIRCRAFT/ SIMULATOR	ORIGINAL FLIGHT HOURS	NEW FLIGHT HOURS	ORIGINAL SIMULATOR HOURS	NEW SIMULATOR HOURS	PERCENT FLIGHT SYLLABUS REOUCTION	FLIGHT SUBSTITUTION RATIO
8. U.S. Army and Human Resources Research Organization/ Caro (1973)	Helicopter Instruments Course/ Undergraduate aviators	UH-1/ 2B24	60.0*	6.5	0.0**	43.0	89	0.8
9. U.S. Coast Guard and Human Resources Research Organization/ Isley, Corley, and Caro (1974)	Search and Rescue Helicopter Qualification Course/Graduate former fixed-wing aviators	H-52/VCTS	78.0	36.1	0.0	21.6	54	0.5
10. U.S. Coast Guard and Human Resources Research Organization/ Isley, Corley, and Caro (1974)	Search and Rescue Helicopter Transition Course/ Graduate helicopter pilots	H-52/VCTS	31.0	27.8	0.0	18.4	10	5.8
11. U.S. Coast Guard and Human Resources Research Organization/ Isley, Corley, and Caro (1974)	Search and Rescue Helicopter Transition Course/ Graduate helicopter pilots	H-3/VCTS	36.0	23.1	0.0	30.2	36	2.3

* All original group flight hours for obsolescent TH-13 light helicopter.
** Time in Device 1-CA-1 was ignored because it was shown to have negligible transfer (Isley, Caro, and Jolley, 1968).

TABLE 4. MILITARY DEMONSTRATIONS: HELICOPTERS (continued)

ENVIRONMENT			SUBSTITUTION DATA				COMPUTED RESULTS	
ORGANIZATION/ REFERENCE	TASK/ STUDENTS	AIRCRAFT/ SIMULATOR	ORIGINAL FLIGHT HOURS	NEW FLIGHT HOURS	ORIGINAL SIMULATOR HOURS	NEW SIMULATOR HOURS	PERCENT FLIGHT SYLLABUS REDUCTION	FLIGHT SUBSTITUTION RATIO
12. U.S. Air Force 1550th Aircrew Training and Test Wing/ Aerospace Rescue and Recovery Service (1974)	Search and Rescue Helicopter Transition Course/ Graduate helicopter pilots	H-3/T-42	63.0*	37.0	0.0	19.0	41	0.7

* 44 hours in the H-3 and 19 hours in the TH-1 training helicopter.

training curriculum, simulator (VCTS), and airframe (H-52) were the same with the only difference being the previous flight experience of the students.

Demonstration 12 achieved a moderate degree of substitution. In this demonstration the Air Force obtained a better substitution ratio than did the Coast Guard in demonstration 11 for the same airframe (H-3). In both demonstrations a new curriculum was developed emphasizing the simulator. These curriculums included specific training objectives with self-paced, proficiency-based, advancement for students.

JETS. Demonstrations 13 through 18 in table 5 describe substitution practices in Undergraduate Pilot Training (UPT) utilizing fighter-type jet trainers. Three U.S. Air Force demonstrations (13, 14, and 15) were included in this description of current practices even though they employ research-oriented devices (T-4G and the Advanced Simulator for Undergraduate Pilot Training (ASUPT)). They are included here because the results of these well-conducted studies have influenced the design of an operational training device, the Instrument Flight Simulator (IFS). The latter could be viewed as an operational version of the research devices used in these studies.

The results of the two T-37/T-4G demonstrations (13 and 14) were consistent with the general trend of larger percentage savings for instrument vs. contact tasks. The negative FSR obtained in the instrument course was due to the unusual circumstances of a simultaneous decrease in both simulator and flight time. These two studies employed a simulator with modest visual and motion systems. A third U.S. Air Force T-37 demonstration (15) utilized the ASUPT. This is a new and highly sophisticated simulator equipped with wide angle visual and large amplitude (six degrees of freedom) motion system, G-seat, and G-suit. This demonstration incorporated both the contact and instrument tasks of the U.S. Air Force basic jet curriculum. The resultant savings for the program achieved a level between the values reported in previous T-37 demonstrations (13 and 14). All three T-37 studies used a new syllabus designed to make maximum use of new simulator capabilities. Although the programs employed self-paced, proficiency-based, advancement, their use was restricted to "new simulator" groups. This differential treatment may have increased the substitution values achieved by the new simulator groups over respective "original simulator" groups.

The TA-4/2F90 aircraft and flight simulator combination is used in several stages of U.S. Navy and U.S. Marine Corps advanced jet training. Table 5 presents three demonstrations from this program (16, 17, and 18) involving instrument training. Increased simulation use in demonstrations 16 and 17 achieved approximately 50 percent flight syllabus reduction over the traditional syllabus groups. This figure was consistent with that obtained in the U.S. Air Force jet instruments

TABLE 5. MILITARY DEMONSTRATIONS: JETS

ENVIRONMENT			SUBSTITUTION DATA				COMPUTED RESULTS	
ORGANIZATION/ REFERENCE	TASK/ STUDENTS	AIRCRAFT/ SIMULATOR	ORIGINAL FLIGHT HOURS	NEW FLIGHT HOURS	ORIGINAL SIMULATOR HOURS	NEW SIMULATOR HOURS	PERCENT FLIGHT SYLLABUS REDUCTION	FLIGHT SUBSTITUTION RATIO
13. U.S. Air Force Human Resources Laboratory/ Woodruff, Smith, and Morris (1974)	Basic Jet Course, Contact Phase/ Undergraduate pilots	T-37/T-4G	27.2	23.2	0.0	14.9	15	3.7
14. U.S. Air Force Human Resources Laboratory/ Woodruff, Smith, and Morris (1974)	Basic Jet Course, Instrument Phase/ Undergraduate pilots	T-37/T-4G	20.8	9.7	23.4	14.9	53	-0.8
15. U.S. Air Force Human Resources Laboratory/ Woodruff, Smith Fuller, and Weyer (1976)	Basic Jet Course/ Undergraduate pilots	T-37/Advanced Simulator for Undergraduate Pilot Training	91.3	70.7	17.0	59.4	23	2.1
16. U.S. Navy Chief of Naval Air Training and Naval Training Equipment Center/Ryan, Puig, Micheli, and Clark (1972)	Advanced Jet Course, Basic Instrument Phase/ Undergraduate U.S. Navy and U.S. Marine Corps pilots	TA-4/2F90	8.5	4.1	7.1	8.7	52	0.4

TABLE 5. MILITARY DEMONSTRATIONS: JETS (continued)

ENVIRONMENT			SUBSTITUTION DATA				COMPUTED RESULTS	
ORGANIZATION/ REFERENCE	TASK/ STUDENTS	AIRCRAFT/ SIMULATOR	ORIGINAL FLIGHT HOURS	NEW FLIGHT HOURS	ORIGINAL SIMULATOR HOURS	NEW SIMULATOR HOURS	PERCENT FLIGHT SYLLABUS REDUCTION	FLIGHT SUBSTITUTION RATIO
17. U.S. Navy Chief of Naval Air Training and Naval Training Equipment Center/ O'Connor and Glennon (1973)	Advanced Jet Course, Basic Instruments and Instrument Navigation Phases/ Undergraduate U.S. Navy and U.S. Marine Corps pilots	TA-4/2F90	35.3	18.8	21.0	27.0	46	0.4
18. U.S. Navy Chief of Naval Air Training and Naval Training Equipment Center/ O'Connor and Glennon (1973)	Advanced Jet Course, Basic Instruments and Instrument Navigation Phases/ Undergraduate U.S. Navy and U.S. Marine Corps pilots	TA-4/2F90	35.3*	35.8*	21.0*	0.0*	1	42.0

* The computational formulas (in table 1) assume increased simulator time for the "new" program over that of the "original" program. Thus, to prevent spurious negative computed results, the order of entering data in these formulas was reversed in this calculation.

demonstration (14) reported earlier. However, simulator efficiencies (FSRs) were markedly better in the Navy studies.

In contrast to the usual practices of increasing simulator time, demonstration 18 attempted to determine the implications of total elimination of simulator time. A comparison of the flight-only group with a previous traditional-syllabus group indicated that the former required only 0.5 hours more flight time. This resulted in an FSR of 42.0 which was several orders of magnitude higher than those obtained in demonstrations 16 and 17.

TRANSPORTS. A third major category of military substitution practice provided data that were based on demonstrations which involved military pilots, a range of simulator capabilities, and multiengine fixed-wing aircraft.

Demonstrations 19 and 20 in table 6 involve the use of the Navy P-3 aircraft and the 2F69 simulator. The purpose of demonstration 19 was to improve simulation utilization through modification of syllabus and instructional techniques. The data from demonstration 20, on the other hand, were generated from a situation where the simulator time was available from previous training; the flight-only group information was the consequence of a class being trained during a squadron relocation which temporarily eliminated use of the simulator. The formal effort (19) to explore simulator substitution resulted in far better efficiency (FSR) and effectiveness (syllabus reduction) than the more informally generated data of the companion demonstration (20).

Demonstration 21 provides data on Device 2F87F, P-3C Operational Flight Trainer. The study was concerned with an assessment of the effectiveness of the device as a substitute for the current analog operational flight trainer used in combination with the P-3 aircraft. The 2F87F high-fidelity digital device is equipped with a six degrees of freedom motion and a narrow angle television model-board visual system. The device when used in a block training regime for the familiarization/instrument phase of transition training was an effective substitute for 9.0 hours of training in the older analog device and 6.4 hours of in-flight training in the P-3 aircraft. This represents a 43 percent reduction of aircraft training time and provided an FSR of 2.3.[3] A significant finding of this study was the reported transfer of training for the landing task (a reduction of 16 landings required for qualification). No previous studies are known to have reported transfer of training from the simulator to the aircraft for this task.

[3] The relatively high FSR results from the addition of approximately 12 hours training given each pilot in copilot tasks not trained or checked in the aircraft.

TABLE 6. MILITARY OEMONSTRATIONS: TRANSPORTS

ENVIRONMENT			SUBSTITUTION DATA				COMPUTEO RESULTS	
ORGANIZATION/ REFERENCE	TASK/ STUDENTS	AIRCRAFT/ SIMULATOR	ORIGINAL FLIGHT HOURS	NEW FLIGHT HOURS	ORIGINAL SIMULATOR HOURS	NEW SIMULATOR HOURS	PERCENT FLIGHT SYLLABUS REOUCTION	FLIGHT SUBSTITUTION RATIO
19. U.S. Navy Patrol Squadron 30 and Training Analysis and Evaluation Group (TAEG)/ Browning, Ryan, and Scott (1973)	Transition Course, Four-Engine Turboprop/ 1st tour graduate pilots	P-3/2F69	19.3	11.8	11.0	13.5	39	0.3
20. U.S. Navy Patrol Squadron 30/Class Progress Records (1975) and Personal Communications (1976)	Transition Course, Four-Engine Turboprop/1st tour graduate pilots	P-3/2F69	16.4*	15.0	0.0*	9.0	9	6.4
21. U.S. Navy Patrol Squadron 30 and TAEG/ Browning, Ryan, Scott, and Smode (1977)	Transition Course, Four-Engine Turboprop/ 1st tour graduate pilots	P-3/2F87F	15.0	8.6	9.0**	24.0	43	2.3
22. U.S. Navy Airborne Early Warning Squadrons 110 and 120/Personal Communications (1976)	Transition Course, Twin-Engine Carrier Based Turboprop/ 1st tour graduate pilots	E-2/2F65	61.0	67.5	0.0	15.0	-11	∞

* Information based on one class (7510) trained during period when simulator was unavailable due to squadron relocation.
** Hours in earlier generation flight simulator Oevice 2F690.

TABLE 6. MILITARY DEMONSTRATIONS: TRANSPORTS (continued)

ENVIRONMENT			SUBSTITUTION DATA				COMPUTED RESULTS	
ORGANIZATION/ REFERENCE	TASK/ STUDENTS	AIRCRAFT/ SIMULATOR	ORIGINAL FLIGHT HOURS	NEW FLIGHT HOURS	ORIGINAL SIMULATOR HOURS	NEW SIMULATOR HOURS	PERCENT FLIGHT SYLLABUS REDUCTION	FLIGHT SUBSTITUTION RATIO
23. U.S. Air Force 4442th Combat Crew Training Wing and Human Resources Laboratory/ Valverde and Burkett (1971) and Personal Communications (1976)	Transition Course, Four-Engine Turboprop/ 1st tour graduate pilots	C-130/T-19	22.5	17.5	30.0	32.0	22	0.4
24. U.S. Air Force 443rd Military Airlift Wing/ Operational Test and Evaluation Report (1974) and Personal Communications (1976)	Transition Course, Four-Engine Jet/1st tour graduate pilots	C-141/T-37A	17.1	14.5	0.0	40.0	15	15.4
25. U.S. Army and Human Resources Research Organization/ Caro, Isley, and Jolley (1973)	Transition and Instrument Qualification Course, Piston Powered, Light Twin/Undergraduate aviators	T-42/GAT-2	60.0	35.0	21.0*	25.0	42	0.2

* Hours in generalized instrument training Device 2B12A.

Demonstration 22 contains data obtained from a comparison of two U.S. Navy squadrons which fly the same basic aircraft. One squadron employed a flight simulator while the second relied on a Cockpit Procedures Trainer (CPT). The unit without the simulator (2F65) required 6.5 hours less flight time to transition pilots. No significant difference in piloting tasks, syllabi, or training requirements which could have contributed to this finding was evident. However, the 2F65 simulator was not state-of-the-art, lacked a visual system, and had only a limited motion system.

Two U.S. Air Force demonstrations (23 and 24) involved heavy transports and state-of-the-art simulators (T-19 and T-37A). Similar to the previous Navy P-3 aircraft demonstrations (19 and 20), the formally supervised demonstration (23) achieved substitution superior to a less formal demonstration (24). In particular, simulator efficiency (FSR) was better for the formally supervised demonstrations.

The final demonstration (25) differed from the other transport studies in that it involved a light twin-engine transport (T-42) and U.S. Army undergraduate pilots. The substitution values obtained in this demonstration were superior to most other military transport programs cited in table 6. The simulator group in this demonstration used a twin-engine General Aviation Trainer (GAT-2) while the comparison group utilized the lower fidelity generalized instrument trainer (2B12A). However, this significant savings was obtained only after a syllabus modification based on the new device's capabilities was introduced.

SECTION IV

SYNOPSIS AND FACTOR COMPARISONS

This section summarizes the demonstration data as a function of training category, user class, type aircraft, student experience, simulator capabilities, and curriculum features. Initially, a tabular format is used to provide a synopsis of the factors indigenous to each of the demonstrations. This is followed by a series of tables in which comparisons of effectiveness (percent flight syllabus reduction) and efficiency (flight substitution ratio) associated with various factors in the demonstrations are presented.

SYNOPSIS

Table 7 summarizes the demonstrations in terms of their significant situational factors. The table also presents data on the percent flight syllabus reduction and the flight substitution ratio for each demonstration. The factors form the bases of substitution effectiveness and efficiency comparison in subsequent parts of this section. Although additional factors could have been examined, these six factors were of primary interest in the present effort. Only generalized factors have been employed because more specific identifications would render comparisons impossible due to paucities of data at finer levels of analysis. Even with these limitations, there are 1,296 potential combinations of the parameters in table 7. The 1,296 combinations are computed as follows: 3 training categories X 3 user classes X 3 types of aircraft X 3 student experience levels X 4 simulation capabilities X 4 curriculum features. This complexity suggests the high degree of caution required in interpreting the data.

COMPARISONS OF EFFICIENCY AND EFFECTIVENESS

An examination of the factors involved in the demonstrations suggested several ways of summarizing the data. In the following tables, the studies were grouped in various ways in accordance with the presence or absence of the major factors. The median values for flight syllabus reductions and substitution ratios were computed on the groupings. Descriptive rather than inferential statistics were used in these comparisons because of data limitations. The skewed raw data suggested that comparing median values was the most appropriate method of analysis.

TRAINING CATEGORY COMPARISONS. Pure instrument tasks resulted in larger percent saving and more favorable (i.e., smaller) FSRs than contact/familiarization type tasks (table 8). The median savings for demonstrations utilizing both types of training fell between the values for instrument and contact/familiarization tasks.

TABLE 7. SYNOPSIS OF DEMONSTRATIONS

DEMONSTRATION NUMBER	TRAINING CATEGORY	USER CLASS	TYPE AIRCRAFT	STUDENT* EXPERIENCE	SIMULATOR CAPABILITIES	CURRICULUM FEATURES	PERCENT FLIGHT SYLLABUS REDUCTION	FLIGHT SUBSTITUTION RATIO
1	Contact/Fam	General Aviation	Light Plane	Undergraduate	-	Special Syllabus	20	1.2
2	Contact/Fam	General Aviation	Light Plane	Undergraduate	-	Special Syllabus	24	1.0
3	Contact/Fam	General Aviation	Light Plane	Undergraduate	-	-	16	2.3
4	Instruments	General Aviation	Light Plane	Graduate	-	-	48	0.9
5	Both	Commercial	Transport	Highly Experienced	Visual/Motion	Special Syllabus Part-Task Trainer	93	1.1
6	Both	Commercial	Transport	Highly Experienced	Visual/Motion	Special Syllabus Part-Task Trainer	95	0.9
7	Both	Commercial	Business Jet	Highly Experienced	Visual/Motion	Special Syllabus Part-Task Trainer	72	2.8
8	Instruments	Military	Helicopter	Undergraduate	Motion	Special Syllabus	89	0.8
9	Both	Military	Helicopter	Graduate	Motion	Special Syllabus Part-Task Trainer	54	0.5
10	Both	Military	Helicopter	Graduate	Motion	Special Syllabus Part-Task Trainer	10	5.8
11	Both	Military	Helicopter	Graduate	Motion	Special Syllabus	36	2.3
12	Both	Military	Helicopter	Graduate	Motion	Special Syllabus Part-Task Trainer	41	0.7
13	Contact/Fam	Military	Jet	Undergraduate	Visual/Motion	Special Syllabus	15	3.7
14	Instruments	Military	Jet	Undergraduate	Visual/Motion	Special Syllabus	53	-0.8
15	Both	Military	Jet	Undergraduate	Visual/Motion	Special Syllabus	23	2.1
16	Instruments	Military	Jet	Undergraduate	Motion	-	52	0.4
17	Instruments	Military	Jet	Undergraduate	Motion	-	46	0.4
18	Instruments	Military	Jet	Undergraduate	Motion	-	01	42.0
19	Both	Military	Transport	Graduate	Motion	Special Syllabus Part-Task Trainer	39	0.3
20	Both	Military	Transport	Graduate	Motion	-	09	6.4
21	Both	Military	Transport	Graduate	Visual/Motion	-	43	2.3
22	Both	Military	Transport	Graduate	-	-	-11	∞
23	Both	Military	Transport	Graduate	Motion	Special Syllabus Part-Task Trainer	22	0.4
24	Both	Military	Transport	Graduate	Visual/Motion	Part-Task Trainer	15	15.4
25	Both	Military	Light Transport	Undergraduate	Motion	Special Syllabus	42	0.2

* Graduate refers to demonstrations involving designated military pilots and licensed general aviation pilots in one instrument training course. Undergraduate refers to military UPT programs and general aviation student pilot training programs.

TABLE 8. SUMMARY OF SUBSTITUTION DATA FOR TRAINING CATEGORIES

Categories	Number of Comparison Demonstrations	Median Percent Flight Syllabus Reduction	Median Flight Substitution Ratio
Contact/ Familiarization	4	18	1.8
Pure Instruments	6	50	0.6
Both	15	39	2.1

USER CLASS COMPARISONS. Commercial airlines were generally able to achieve more effective substitution than other simulator users. The comparisons in table 9 show that commercial airline median syllabus reduction was significantly better than that of other users (93 percent vs. 30 percent). Their FSRs were identical to noncommercial users. The similarity in FSRs may be attributed to differences in transfer efficiency decrements (Povenmire and Roscoe, 1973). That is, as time in the simulator increases, the amount of expected transfer per hour diminishes. Hence, much of the extensive simulator time utilized in commercial settings is spent at asymptotic levels, producing large syllabus reductions but with progressively less impact on FSRs.

TABLE 9. SUMMARY OF USER CLASS SUBSTITUTION DATA

User Classes	Number of Comparison Demonstrations	Median Percent Flight Syllabus Reduction	Median Flight Substitution Ratio
Commercial	3	93	1.1
Noncommercial	22	30	1.1

TYPE OF AIRCRAFT. For the three major military aircraft communities (helicopters, jets, and transports), it was found that simulators were most effectively and efficiently used for helicopter training. Simulators were less successfully utilized in jet fighter-type training and least successfully employed for military transport-type programs. These results are depicted in table 10. This is unexpected in light of the high degree of success which the commercial users have achieved with simulators for similar transport-type airframes (see table 9).

TABLE 10. SUMMARY OF SUBSTITUTION DATA BY TYPE OF AIRCRAFT

Military Aircraft Types	Number of Comparison Demonstrations	Median Percent Flight Syllabus Reduction	Median Flight Substitution Ratio
Helicopters	5	41	0.8
Jets	6	35	1.3
Transports	7	22	2.3

STUDENT EXPERIENCE COMPARISONS. Data in table 11 indicate a larger percent syllabus reduction for recent graduate vs. undergraduate programs. Median syllabi reductions were 36 vs. 24 percent, respectively. However, the rate of substitution was similar. Airline programs were excluded from consideration here because of the extremely high experience levels of their pilots.

TABLE 11. SUMMARY OF SUBSTITUTION DATA FOR STUDENT EXPERIENCE LEVELS

Experience Level	Number of Comparison Demonstrations	Median Percent Flight Syllabus Reduction	Median Flight Substitution Ratio
Graduate	11	36	0.9
Undergraduate	11	24	1.0

Graduate - Refers to demonstrations involving designated military pilots with one exception, licensed general aviation pilots in an instrument training course.

Undergraduate - Refers to eight military UPT programs and three general aviation student training programs.

SIMULATOR CAPABILITY COMPARISONS. For the sake of clarity, the visual and motion parameters of simulator capability are treated separately in this section.

Visual System Comparisons. The comparisons in table 12 provide interesting results in that devices with visual systems achieved greater syllabus reductions than those devices without such systems. However, the median FSR was poorer for devices equipped with visuals (2.2 vs. 0.9). Most studies generally show that visual systems are relatively inefficient for training contact tasks.

TABLE 12. SUMMARY OF SUBSTITUTION DATA FOR VISUAL SYSTEMS

Visual Systems Utilized	Number of Comparison Demonstrations	Median Percent Flight Syllabus Reduction	Median Flight Substitution Ratio
Yes	8	48	2.2
No	17	36	0.9

Motion System Comparisons. The results in table 13 indicate that devices which employed high-fidelity motion platforms achieved much more effective syllabus reduction than those devices which did not employ such systems. Median syllabi reductions were 42 percent for motion equipped devices vs. 16 percent for devices which lacked motion. The FSRs of 1.0 and 1.2 also imply the superiority of motion equipped devices.

TABLE 13. SUMMARY OF SUBSTITUTION DATA FOR MOTION SYSTEMS

Motion Systems Utilized	Number of Comparison Demonstrations	Median Percent Flight Syllabus Reduction	Median Flight Substitution Ratio
Yes	20	42	1.0
No	5	16	1.2

CURRICULUM FEATURE COMPARISONS. Comparisons of the impact of special syllabi and part-task training in conjunction with simulator training are treated separately in this section.

Special Syllabus Comparisons. The development of a special syllabus tailored to the capabilities of a device is generally necessary to maximize the utility of the simulator. Table 14 summarizes the substitution data for demonstrations which employed such special syllabi. For purposes of this summary, demonstrations which restricted the use of self-pacing to the new simulator group are also treated as instances of a special syllabus. Significant reductions were achieved in such special syllabus programs (40 vs. 16 percent). Similarly, the median FSR favors the special syllabus group (1.0 vs. 2.3).

TABLE 14. SUMMARY OF COMPARISONS OF SUBSTITUTION DATA FOR SPECIAL SYLLABI

New Simulator Groups Given Special Training Syllabus	Number of Comparison Demonstrations	Median Percent Flight Syllabus Reduction	Median Flight Substitution Ratio
Yes	16	40	1.0
No	9	16	2.3

Part-Task Trainer Comparisons. A well-conceived and systematic approach to training implies the use of part-task trainers in many situations. The hours spent in these devices were not included in the simulator time data used in this report. Table 15 reveals that substitution figures were better for demonstrations in which part-task training was differentially used in conjunction with the new simulator group (but not with the comparison group). The median syllabi reductions were 41 vs. 30 percent. Likewise, their median FSRs were better with part-task training (0.9 vs. 1.7).

TABLE 15. SUMMARY OF COMPARISONS OF SUBSTITUTION DATA FOR PART-TASK TRAINING

Part-Task Trainers Also Used By New Simulator Groups	Number of Comparison Demonstrations	Median Percent Flight Syllabus Reduction	Median Flight Substitution Ratio
Yes	9	41	0.9
No	16	30	1.7

SECTION V

SUMMARY

This report summarizes 25 representative demonstrations of simulator substitution practices conducted in the past decade. The information obtained from the original documents was of sufficient detail to allow computation of standard substitution indices and interdemonstration comparisons. While many comparisons could have been made of the data obtained from the demonstrations, the following represent a condensation of the most important observations.

- Higher flight syllabus reductions and better flight substitution ratios were attained in instrument tasks than in contact-type tasks.

- Commercial airlines have achieved far better flight syllabus reductions than general aviation or the military.

- Simulators in military programs were most effectively and efficiently utilized for helicopter training. Jet programs were less successful and transport programs were least successful.

- Graduate programs achieved greater flight syllabus reductions and similar flight substitution ratios in comparison with undergraduate programs.

- Simulation devices equipped with visual systems achieved much greater flight syllabus reductions but were less efficient in terms of flight substitution ratios than devices which lacked such systems. That is, they saved greater amounts of flight time than devices without such systems, but they required more hours of simulator time per flight hour saved.

- Devices having high-fidelity motion systems achieved much larger flight syllabus reductions than devices without such systems.

- Greater flight syllabus reductions and more efficient flight substitution ratios were achieved when special syllabi tailored to the simulator were used.

- Part-task trainers utilized in conjunction with new simulators resulted in higher flight syllabus reductions and better flight substitution ratios.

In substance, however, the demonstrations cited indicate substantial ambiguity surrounding these practices and various shortcomings can be identified. The more telling of these are outlined below.

DATA QUALITY

- Substitution data and old syllabi are typically not retained by operational units. The lack of this historic data prohibits before-and-after comparisons of simulator programs.
- Syllabus hours may be inaccurately reported or reasons for syllabus revisions incorrectly attributed to simulator utilization.
- Data often lack specificity in defining training tasks and reporting results. The data are further confounded by simultaneous changes of device, instructional strategy, or curriculum preventing the identification of a specific cause for changes in training hours.
- Contradictions in data involving similar operational contexts may produce dissimilar results because of differential emphasis on flight hour reductions vs. improvements in quality of training.

METHODOLOGICAL PROBLEMS

- The student performance criteria are defined in subjective, ambiguous nonstandard terms. Simulator effectiveness is also often validated against poorly defined, subjective, norm-referenced criteria; e.g., "passed flight check."
- Task or training analyses which are necessary but not sufficient to establish the validity of training requirements are not always performed prior to conducting the demonstration. Such training analyses eliminate irrelevant variables and simplify the assignment problem of tasks to methods.
- The demonstrations are characterized by the lack of a programmatic approach. In essence, each demonstration provided a single "point estimate" of all the feasible simulator hour/flight hour combinations.

DATA INTERPRETATION PROBLEMS

- A single substitution standard does not take cognizance of individual unit needs and could if applied universally impose disproportionate hardships on some units.
- Generalization of findings from one type of operational setting to another should be accomplished cautiously and with full knowledge of situational differences.

The data apply primarily to generalized aviator training such as familiarization, basic and radio instruments, and airways navigation. They cannot always be precisely extrapolated to tactical training tasks.

POST NOTE

This study was undertaken with the expectation that an analysis of current simulator substitution practices would yield insights for selecting substitution ratios for simulator and in-flight training time. Instead, a congeries of problems associated with current practices limited the scope of the original endeavor and precluded any attempts to derive rigorous prescriptions for users. The inability to develop effective guidelines for substitution practices is particularly troublesome in view of the significant costs involved in these decisions.

At present, not much power can be marshaled to provide satisfactory guidelines for employing simulator training as a surrogate for in-flight training. However, the role of simulation in flight training is receiving considerable attention today, generated not only by an awareness of increasing training simulator capabilities but by economic pressures as well. Systematic efforts to put the substitution issue in perspective are underway.

Several major programs concerned with optimizing simulator utilization in flight training are currently underway. The TAEG is continuing its work of efficiently integrating a new state-of-the-art flight simulator into the ongoing training program of a Navy P-3 Replacement Squadron. A study just completed determined the effectiveness of Device 2F87F as a substitute for the earlier generation Device 2F69D in combination with the P-3 aircraft in training replacement patrol plane pilots (Browning, Ryan, Scott, and Smode, 1977). Additional study will examine the contributions of the motion and visual systems to performance, establish a standardized performance assessment capability for the 2F87F, and initiate an effort to implement an automated performance measurement system in the simulator.

The U.S. Air Force has an extensive program of research utilizing the ASUPT at Williams Air Force Base, Arizona. Current research is examining the contribution of large amplitude motion, the G-seat, the G-suit, and wide angle visual simulation to performance.

The Army Research Institute for the Behavioral Sciences utilizing the Synthetic Flight Training System is continuing to establish optimal substitution practices for specific types of helicopters.

To deal with the data resulting from these and other current studies, a center for compiling and organizing simulator substitution data should be established. Its purpose would be to catalog all study efforts and provide a comprehensive data base for the future.

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